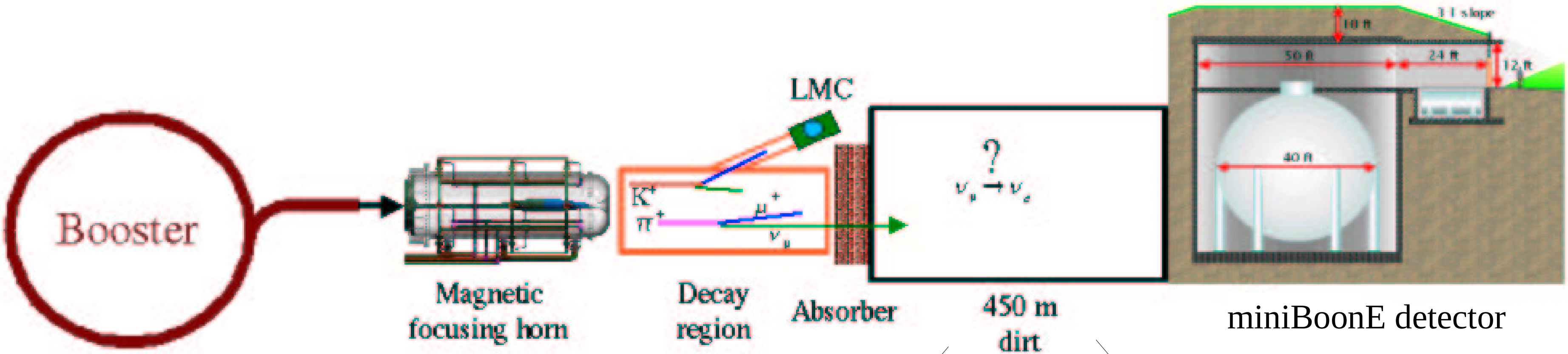
Bonnie T. Fleming
HEP lunch seminar
U. of Chicago
December 16, 2002

FINeSE
Fermilab Intense Neutrino Scattering Experiment

- → FINeSE at Fermilab
- → FINeSE physics
- → timescale and costs

Booster neutrino beamline



horn to focus mesons towards detector

space for a near detector in the Booster neutrino beam

8 GeV protons from FNAL Booster

Decay region: mesons decay to neutrinos

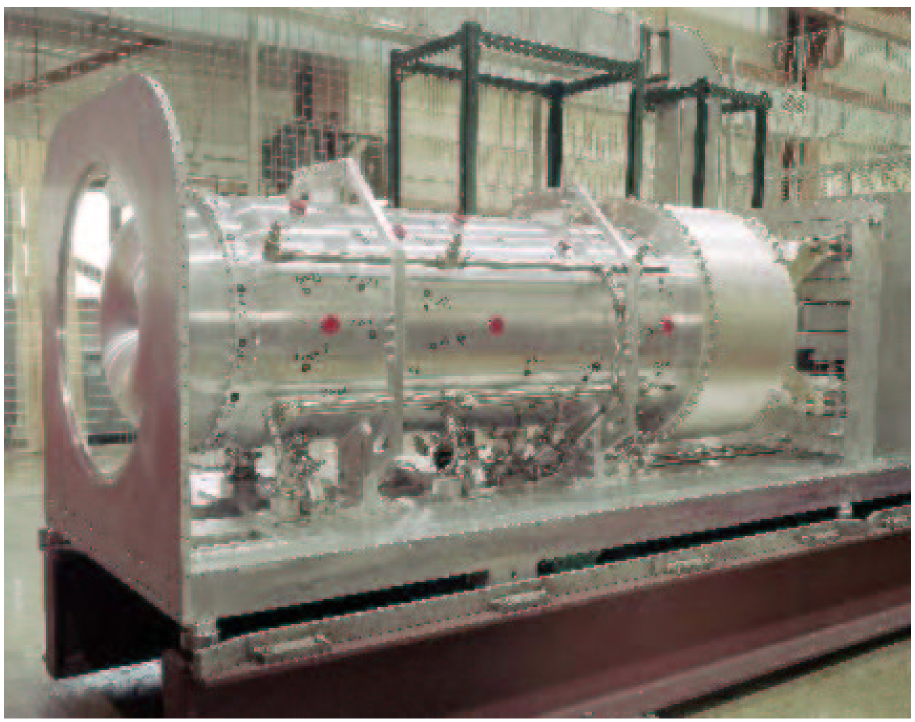
MiniBooNE detector

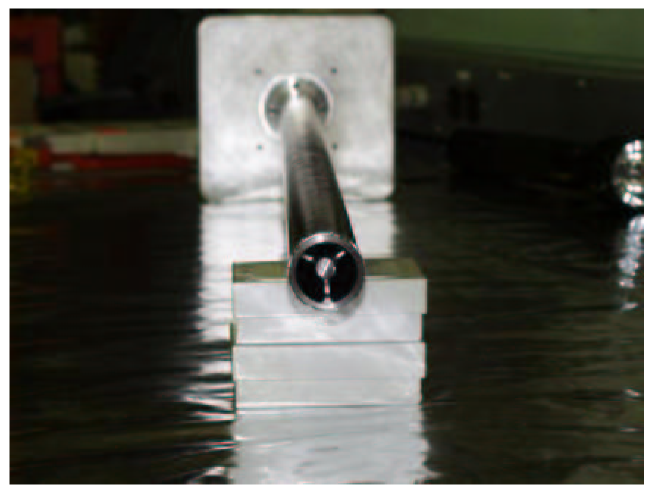
8 GeV beamline

Booster neutrino beamline
to deliver 5 x 10^{20} protons per year

x5 too low right now
→ know what to do to reach intensity

Magnetic focussing horn
>10 million pulses
engineering feat!





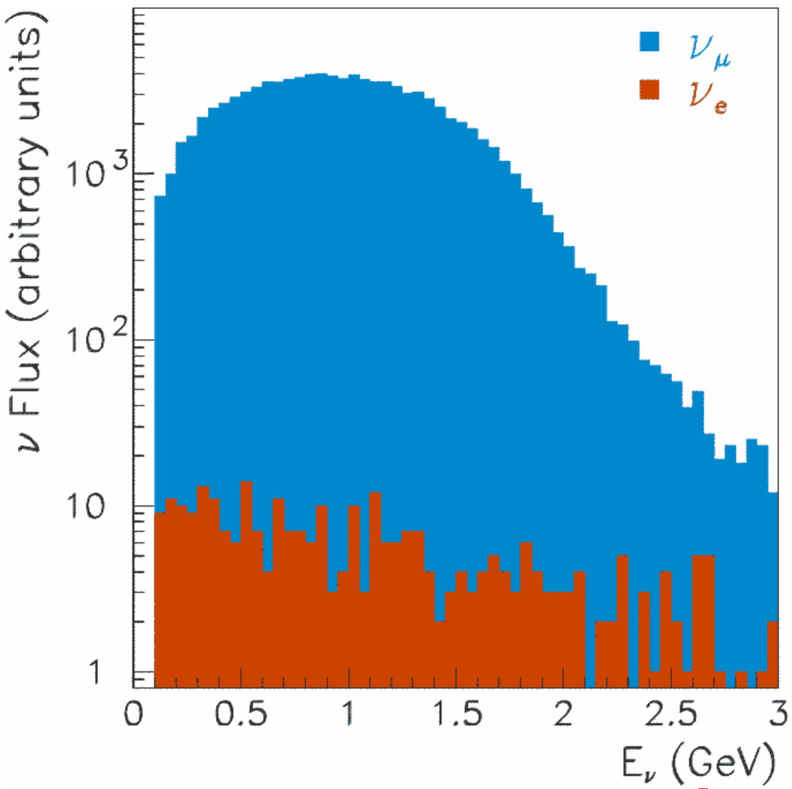
Be target

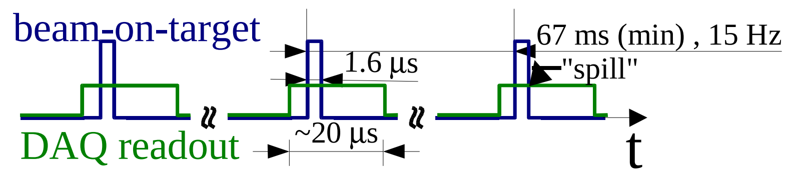
Booster Neutrino Beam flux

intense ν flux

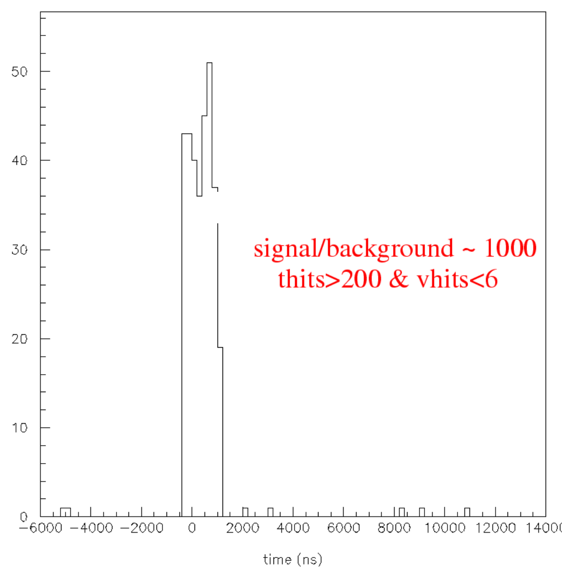
E_ν ~1 GeV

low duty-factor





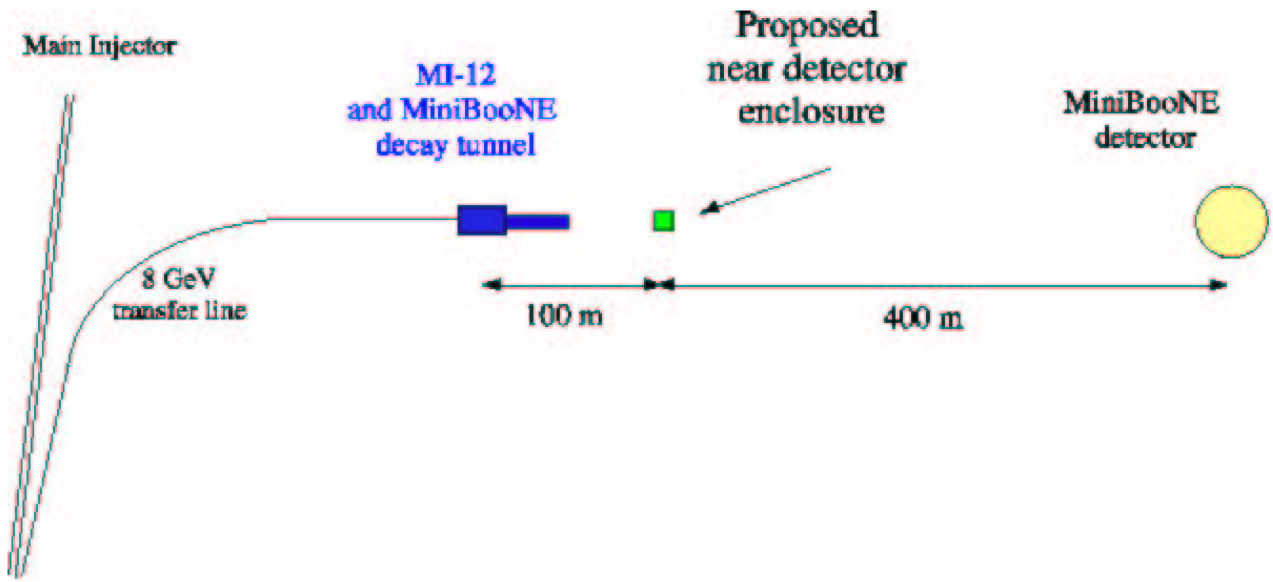
Beam structure



Running, low energy neutrino beam

→ excellent opportunity for ν-physics

FINeSE



Neutrino scattering physics at FINeSE

- strange spin of the proton
- Oscillation physics and miniBooNE
- low energy neutrino cross sections

What do we know about proton spin?

$\sum$ spin of the valence quarks $\neq$ spin of the nucleon

where is it?

sea quarks......gluons......

→

spin carried by the strange sea

why is it distributed like this?

→ fundamental underlying physics?

What might we expect Δs to be?

describe the proton as a superposition of baryon + meson states:

$$|p> = |p_0> + |p_0\pi^0> + |n_0\pi^+> + ...+ |\Lambda_0 k^+> + ...$$

baryon carries spin

$$|\Lambda_0 k^+> \;=\; uds + u\bar{s}$$

whatever spin there is on the strange partons rides on the quarks, not the antiquarks

$$\Delta s = s - \bar{s}$$

should be negative

Δs may help us understand nuclear dynamics

Who has already measured Δs?

Polarized-lepton DIS
(EMC, SMC, SLAC)
results indicate that the fraction of proton spin carried by light quarks:

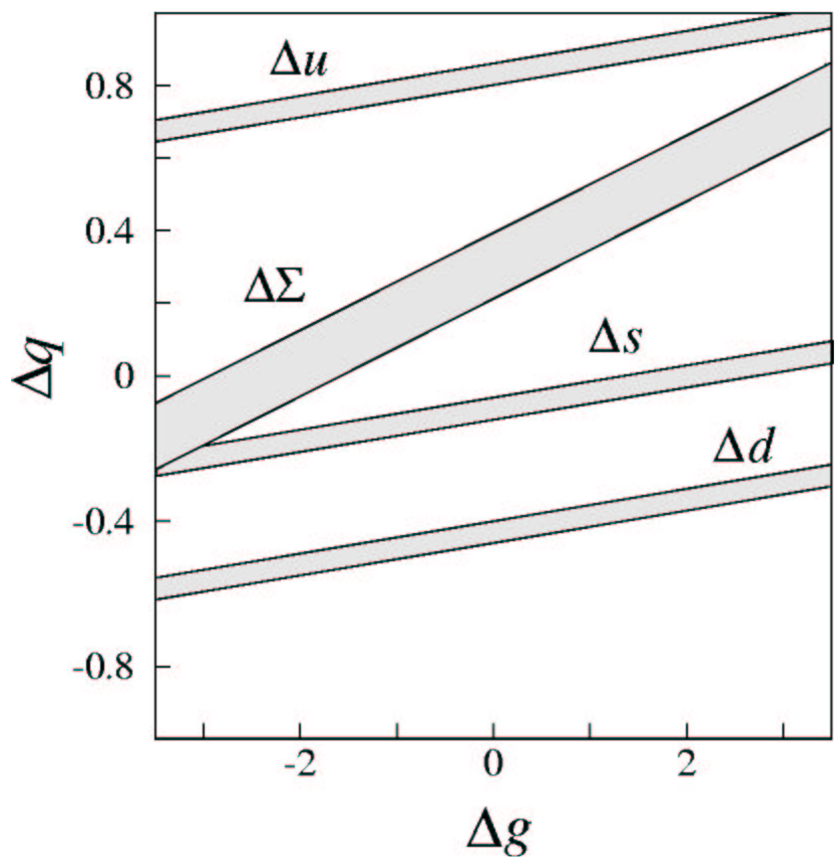
$\Delta\Sigma < 1$ where

nucleon spin=1/2=1/2$\Delta\Sigma$ + ΔG + ΔL_z

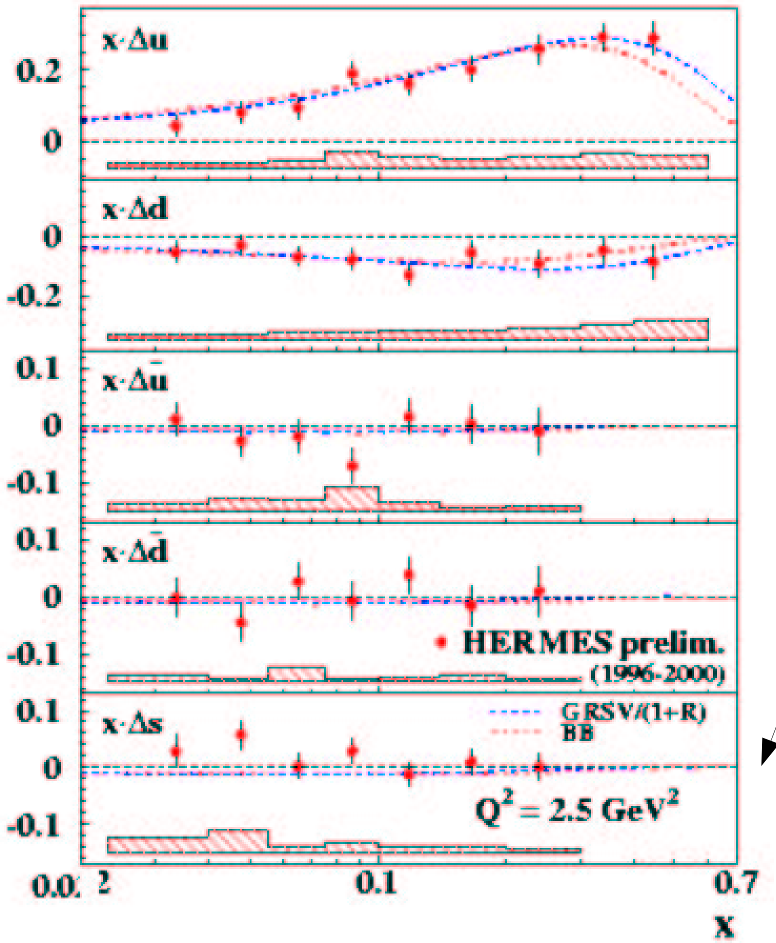
strange contribution

$\Delta s \sim -0.10 \pm 0.05$

→ strongly dependent on assumptions of SU(3) flavor symmetry



Latest results from HERMES*
(semi-inclusive data)



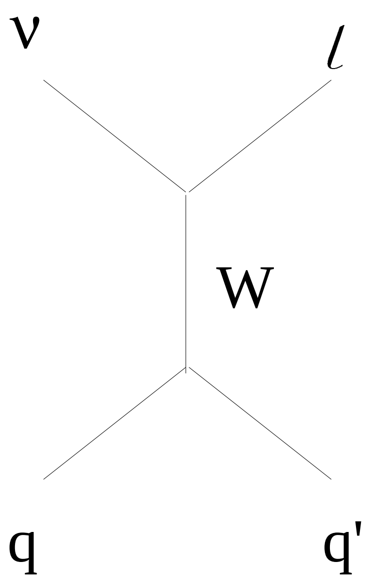
$\Delta s > 0$!

tag π, k, or p in final state in coincidence with scattered lepton

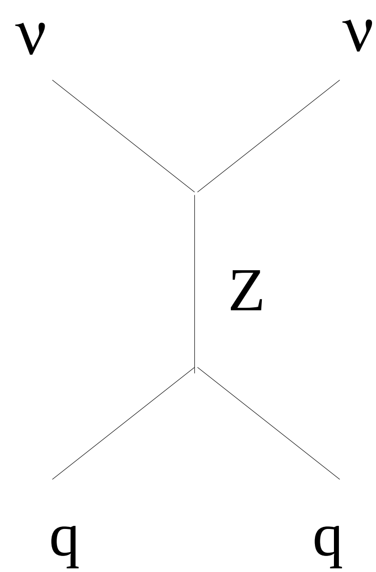
flavor tag helps probe flavor dependence of spin structure

* Int. J. Mod. Phys. A17, 3551, '02.

Measuring Δs using neutrinos



quasi-elastic CC scattering
q=up and down
quarks only



Neutral current scattering
q=any quark in the nucleon
→ strange quarks

Neutrino-nucleon elastic scattering

- Nucleon Neutral Weak Current, J_μ , depends most strongly on G_A (axial) form factor... (somewhat on F_1,F_2)

- $G_A(Q^2) = -\tau_z g_A(Q^2) + G_A^s(Q^2)$
  - g_A known (nuclear β decay)
  - $G_A^s(Q^2=0) = \Delta s$

$\nu p \rightarrow \nu p$ NC cross section at low Q^2

↓

Δs

Problem: 10% error at best on neutrino flux!

Take advantage of cross section *ratios*!

- Ratio of neutral-current elastic scattering on protons to neutrons*:

$$R(p/n) = \sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \nu n)$$

is quite sensitive to G_A^s (Δs) because:

$$G_A = -g_A \tau_z + G_A^s \;, \quad (\tau_z = +1 \text{ p}, -1 \text{ n})$$

However, the systematic errors of neutron detection are problematic. So...

- Ratio of NC elastic scattering to CC quasi-elastic scattering:

$$R(NC/CC) = \sigma(\nu p, NC)/\sigma(\nu p, CC)$$

is somewhat less sensitive to Δs, but experimentally easier.

Very small systematic error due to the uncertainty in neutrino flux!

*(Garvey et al., PR C**48**, 1919, '93)

Measure Δs to level that is done in charged lepton scattering

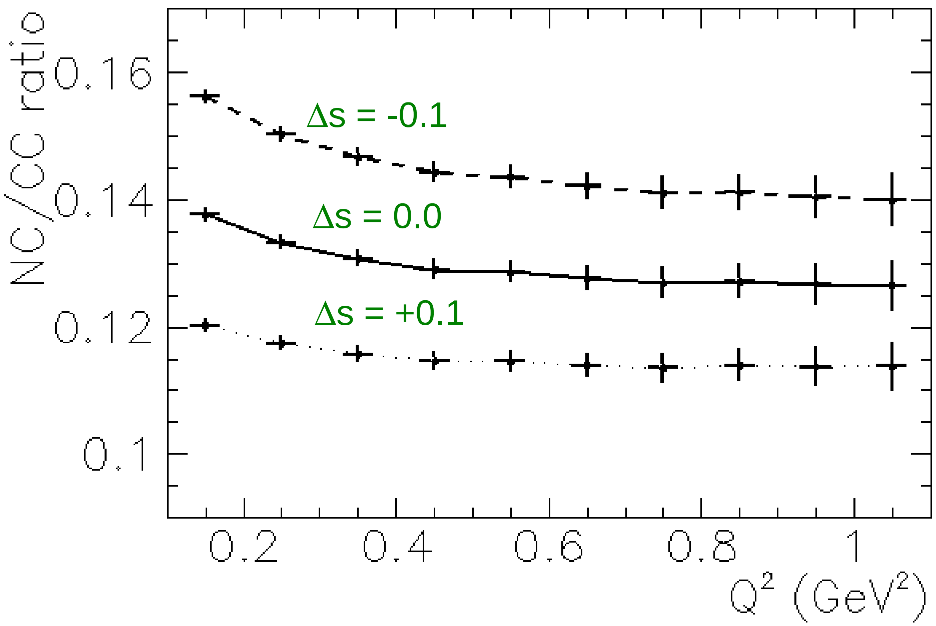
$\sigma(\Delta s) \sim 0.03$

Must measure NC/CC ratio,

$R_{NC/CC} = \sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \mu p)$,

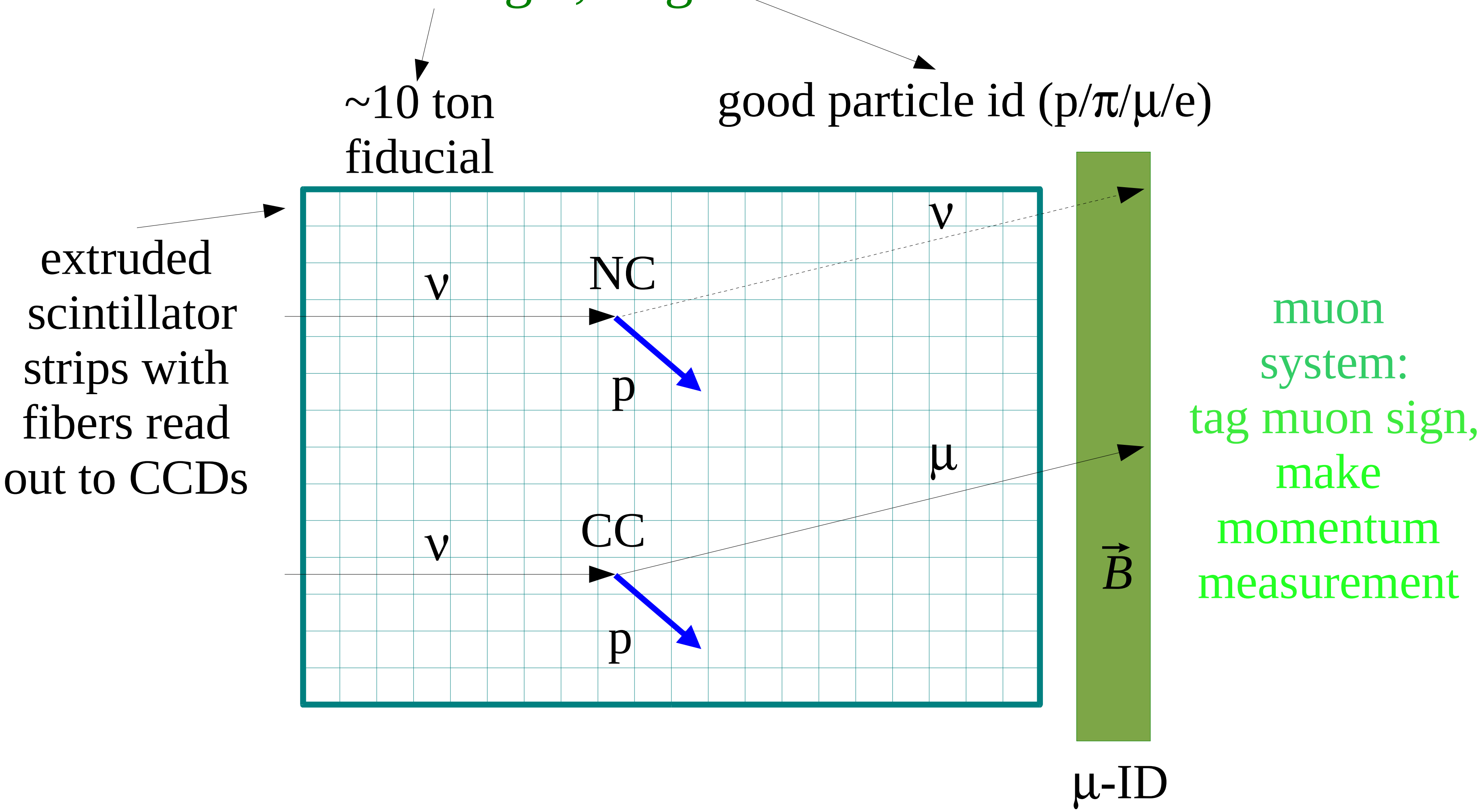
to 5%

NC/CC ratio: (vs Q^2)



Need an active target, segmented, relatively light, detector in an intense ~1 GeV neutrino beam...

Active-target, segmented detector:



Measure NC/CC ratio. The error on ratio is dominated by error on muon detection efficiency:

$$\frac{\epsilon(NC)}{\epsilon(CC)} = \frac{\epsilon(p)}{\epsilon(p)\epsilon(\mu)} = \frac{1}{\epsilon(\mu)}$$

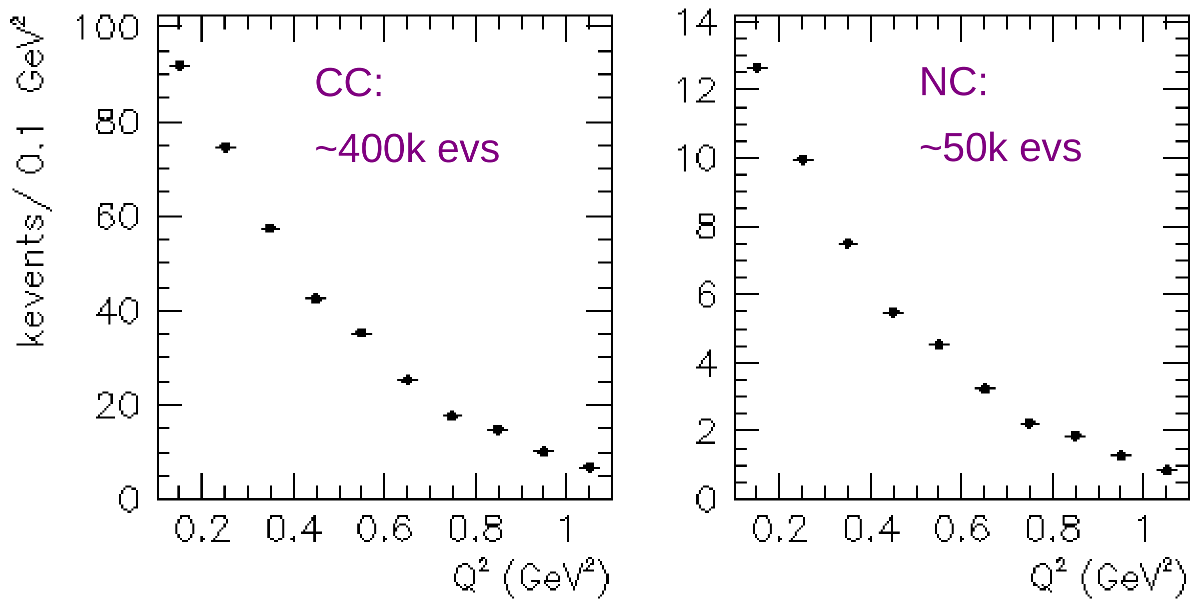
What kind of beam do we need?

Do this at $Q^2 > 0.2$ GeV^2...
- minimize nuclear corrections (Carbon)
- proton detection ($T_p = Q^2/2m_p$)

and $Q^2 < 0.5$ GeV^2...
- minimize worries about Q^2 evolution
- event rates higher as well

10 ton (fiducial) detector, with 5E20 POT, at 100m on Booster ν Beamline

Event Rates: (vs Q^2)



→ can reach goal of NN/CC ratio to 5%

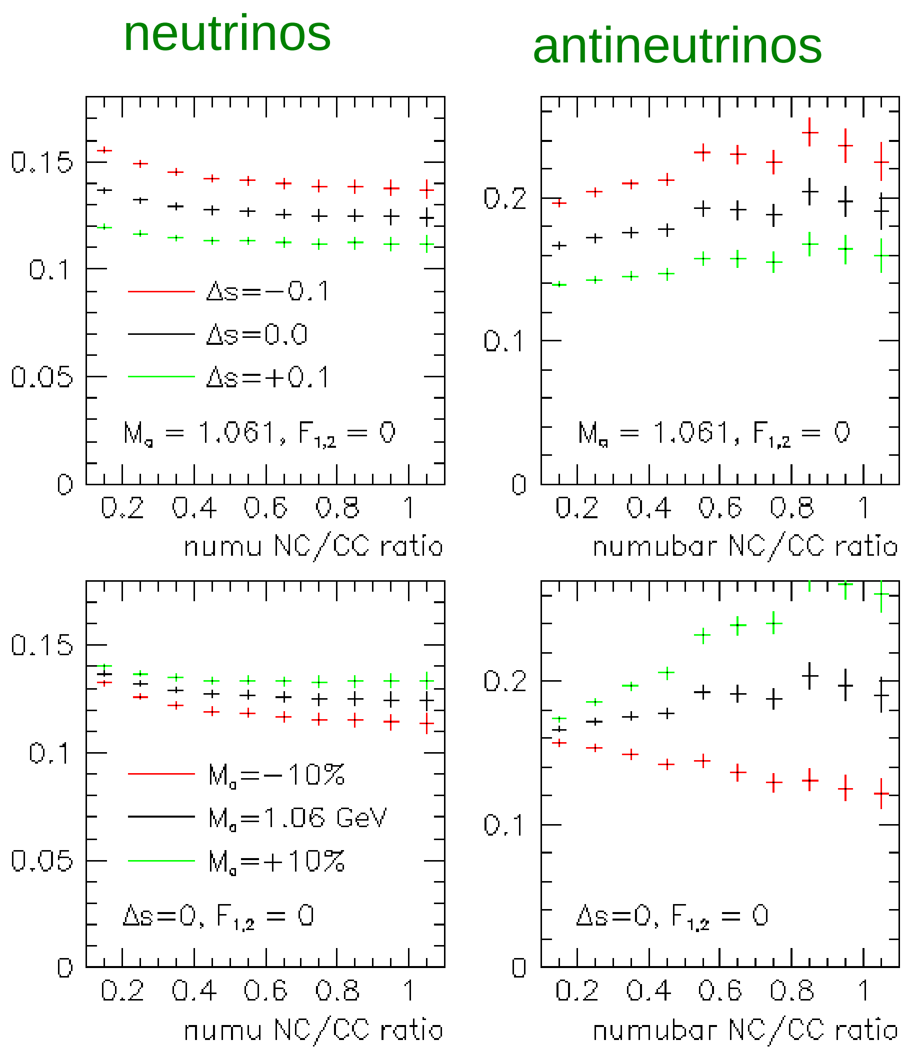
Booster neutrino beamline:

→ sign selecting

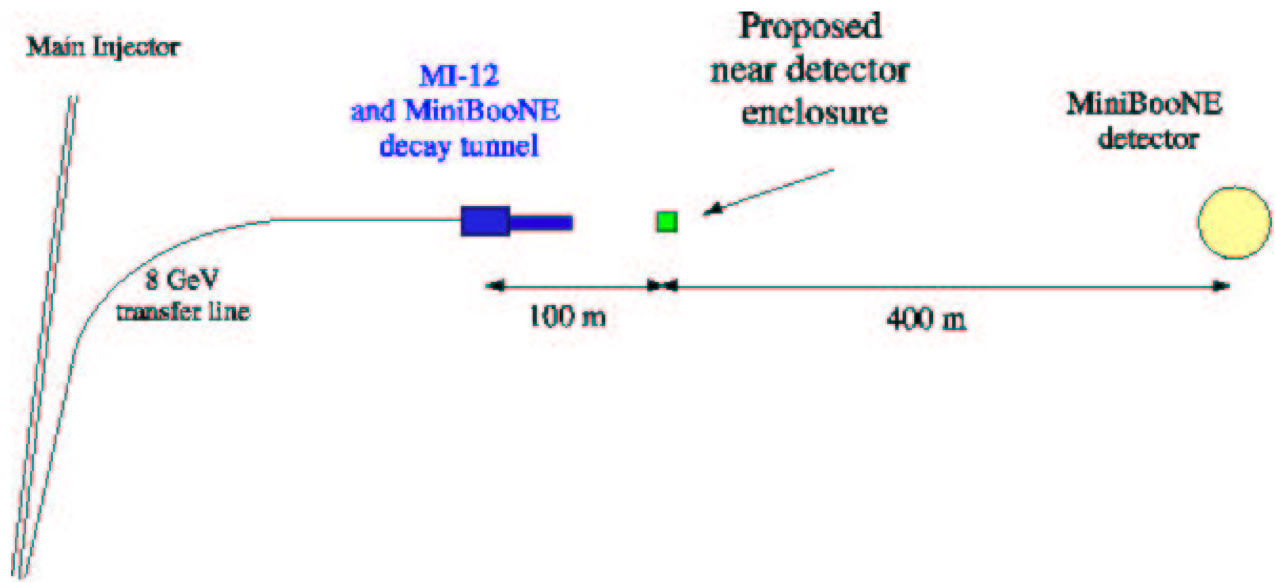
→ neutrinos or anti-neutrinos

Measure NC/CC ratio as a function of Q^2 with neutrinos and antineutrinos

⇒ determine: Δs and μ_s, check: M_A, other systematics



FINeSE and the MiniBooNE program

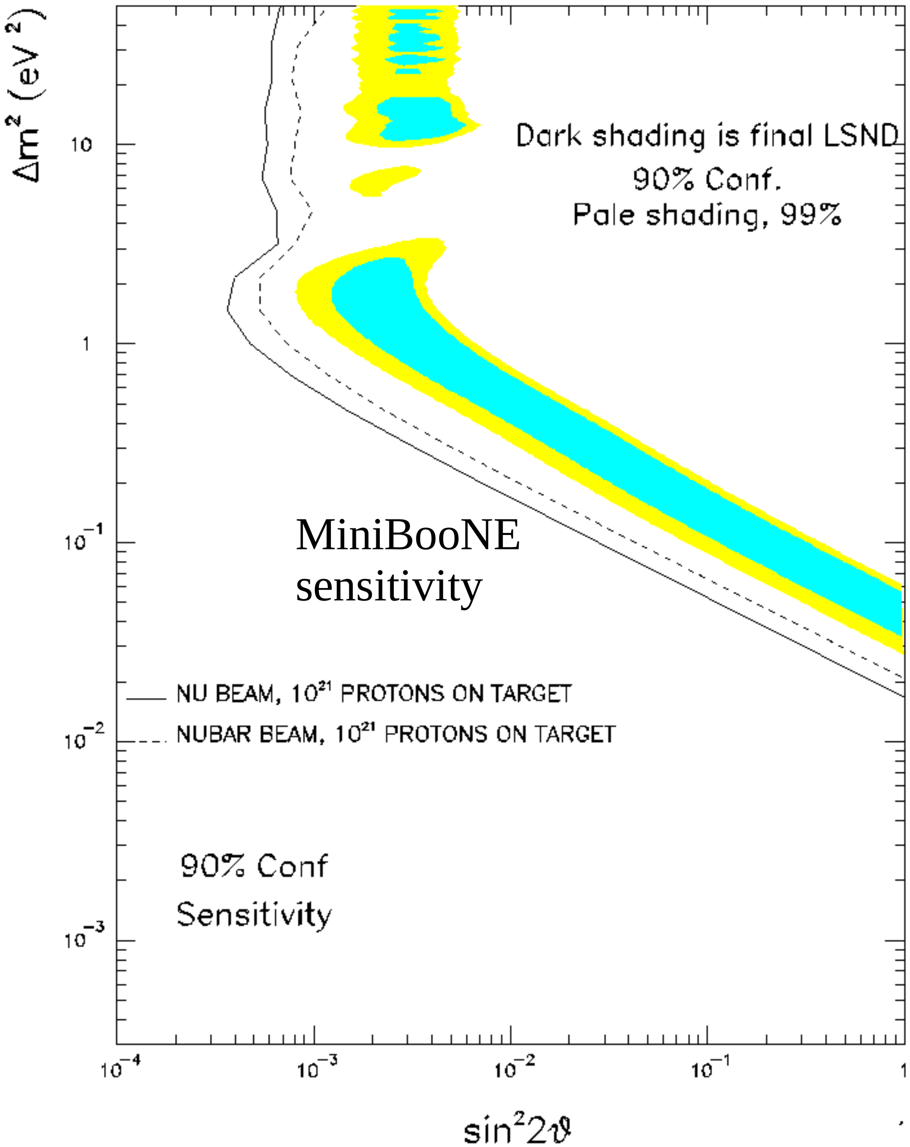


- cross section measurements -- miniBooNE backgrounds
- improving on ν_e appearance sensitivity
- improving on ν_μ disappearance sensitivity

Enhancing the MiniBooNE measurement

If miniBooNE sees a signal, FINeSE will be an important addition in the effort to study the signal

If miniBooNE does not see a signal, FINeSE can push the oscillation search lower in Δm^2 vs. $\sin^2 2\theta$



Improving on the ν_e appearance measurement

FINeSE's final state particle identification

excellent cross section →flux measurements

measure intrinsic beam ν_e rate

3-4%

↓

big improvement over miniBooNE systematic uncertainties for ν_es from muon and kaon decays

→ 7-8%

Improving on the ν_μ disappearance measurement

FINeSE's final state particle identification

excellent cross section $\rightarrow$ flux measurements

ν_μ flux

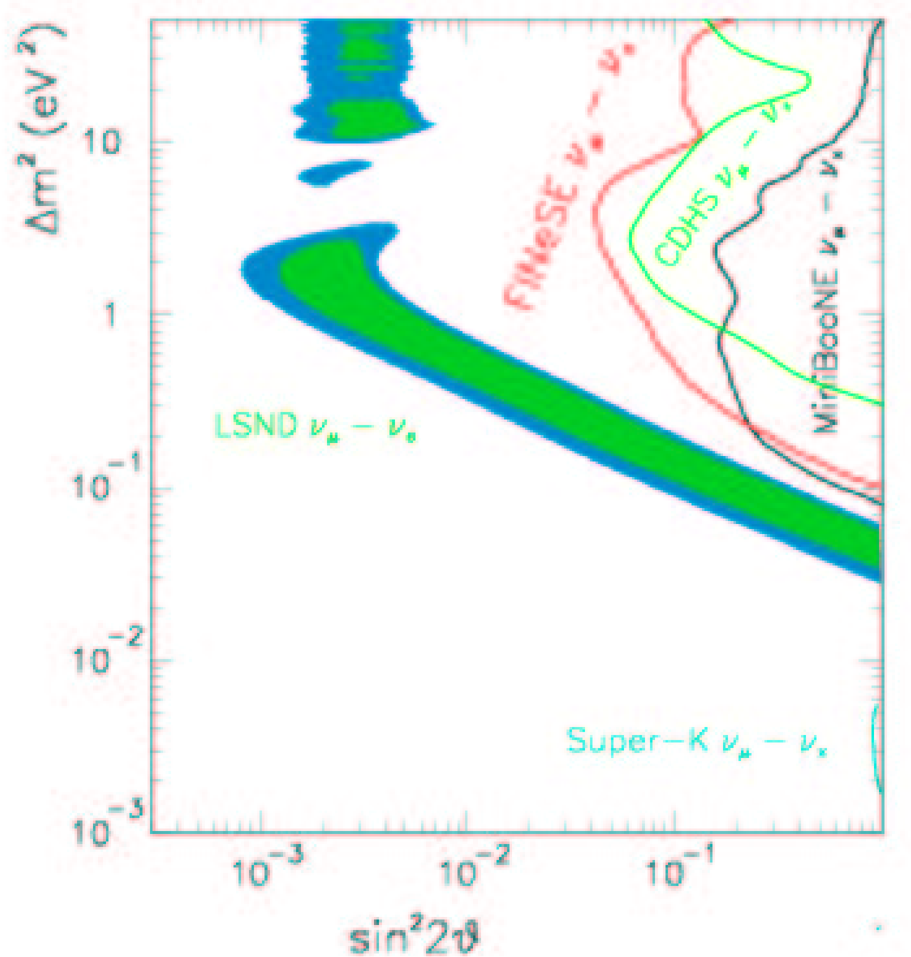
Combined with miniBooNE results

↓

much improved ν_μ disappearance result

few percent level!

Sensitivity of FINeSE+MiniBooNE to ν_μ disappearance



Preliminary!

Cross Section Measurements

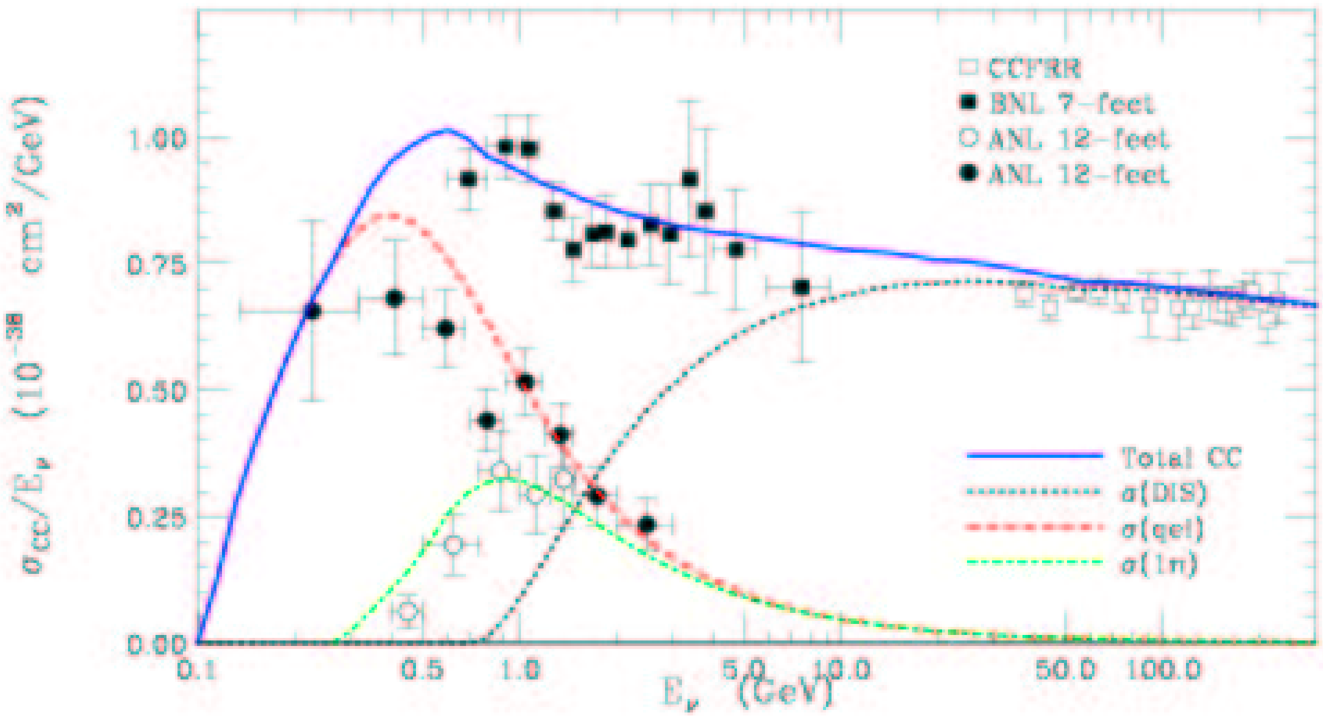
High precision measurements of CC and NC cross sections at Booster neutrino energies

↓

→ neutrino cross sections

→ tests of Standard Model and theories of nucleon structure

Charged current ν_μ cross sections



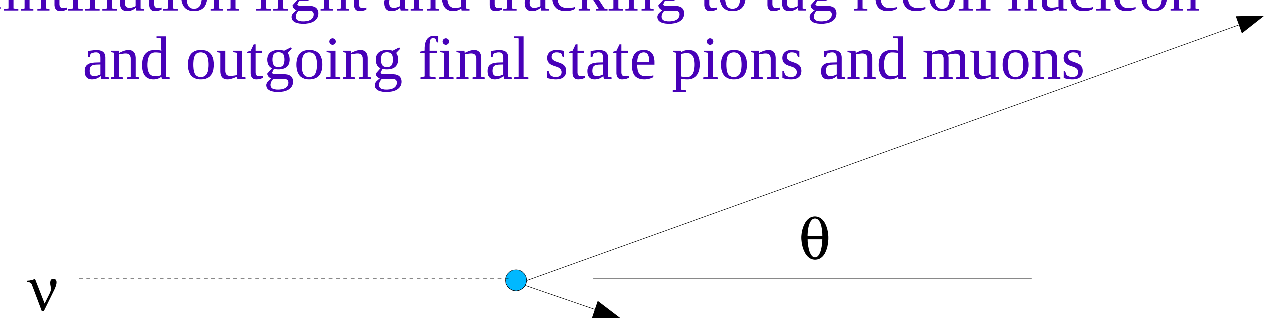
→ study quasi-elastic and single pion cross sections

highly segmented detector
good interaction separation
good energy resolution

This detector is great for measuring these cross sections!

highly segmented detector
good interaction separation
good energy resolution
→
extruded scintillator stack
with fiber readout

Event reconstruction requirements:
scintillation light and tracking to tag recoil nucleon
and outgoing final state pions and muons



for two track events ⟶ calculate
energy of incoming neutrino!

Challenges:

- proton has short range
- muon doesn't

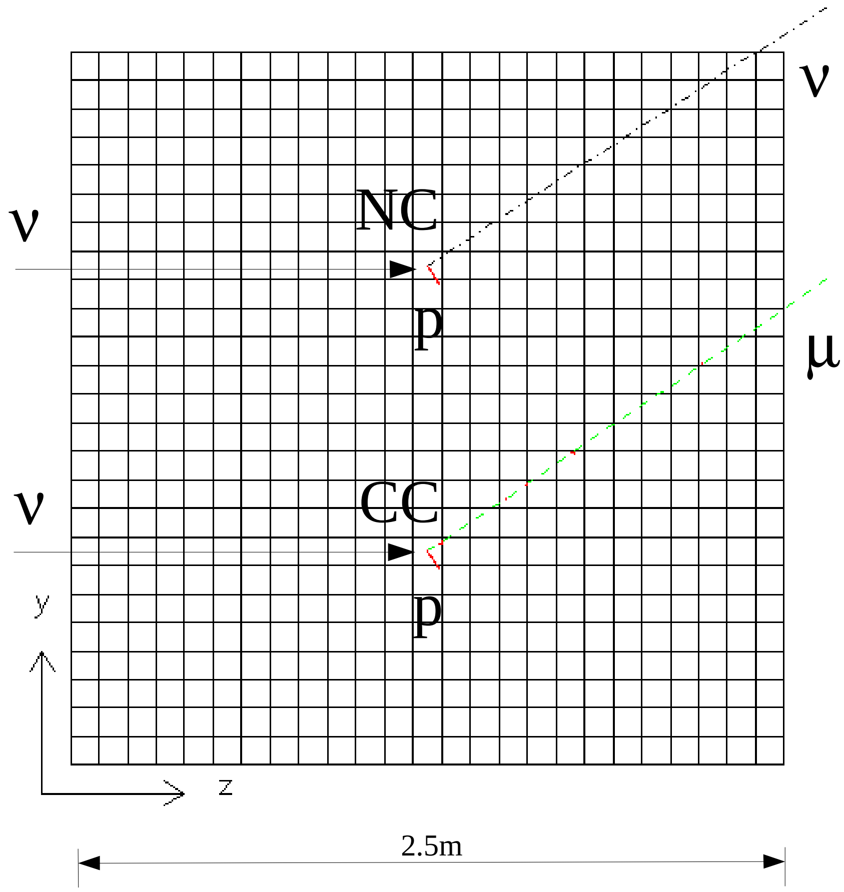
will need:

high segmentation and a muon system

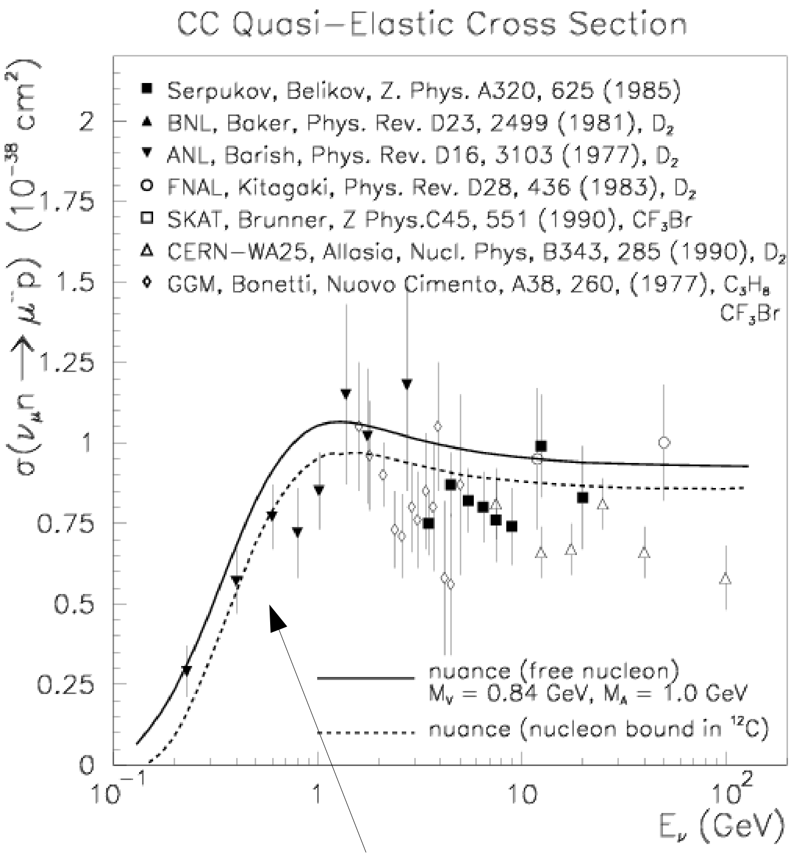
GEANT event:

- $Q^2 = 0.2\ GeV^2$, $E_\nu = 800 MeV$

$T_p \sim 100$ MeV, $T_\mu \sim 600$ MeV,



Charged current quasi-elastic cross section



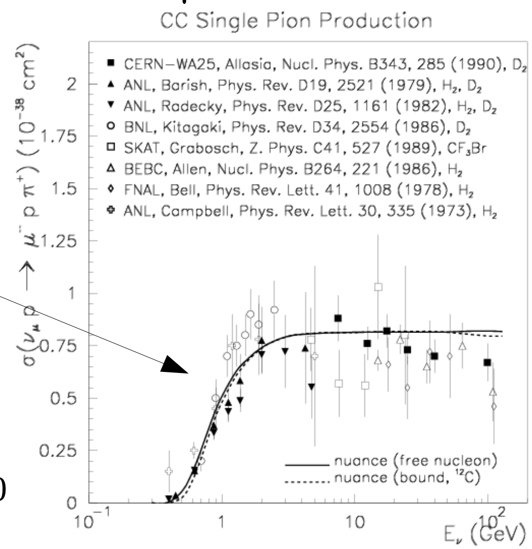
- Most of the data is on light targets
- measurements on relatively heavy targets
  - useful for other neutrino experiments
  - test the nuclear models used to describe this data

→ *Baseline to unfold nuclear effects*

Charged current single pion production

lower energy data
on light targets

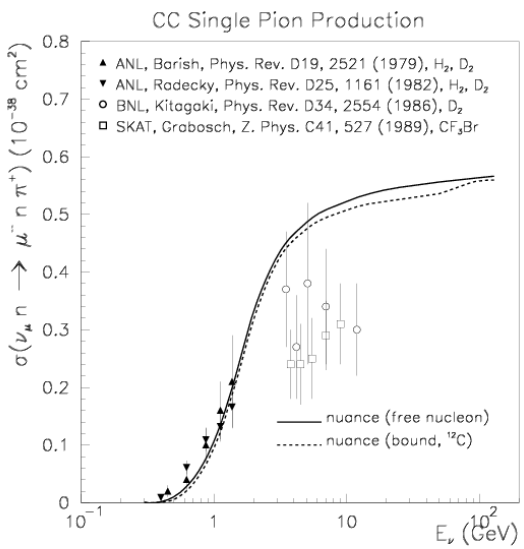
$\nu_\mu p \to \mu^- p \pi^+$



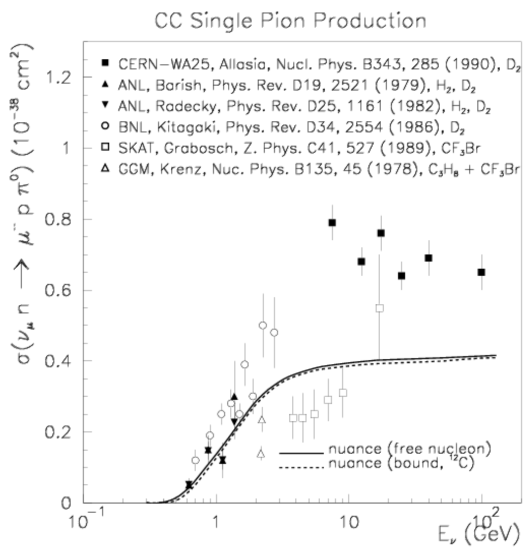
→ *Important new channel to look for ν_e appearance at MiniBooNE*

$\nu_e N \to e N \pi$

$\nu_\mu n \to \mu^- p \pi^0$



$\nu_\mu n \to \mu^- n \pi^+$



Neutral current single pion production

→ almost all neutrino experiments have measured NC/CC ratio

→ Gargamelle experiment reported absolute cross sections

$$\nu_\mu p \rightarrow \nu_\mu p \pi^0$$

$$\nu_\mu n \rightarrow \nu_\mu n \pi^0$$

$$\nu_\mu n \rightarrow \nu_\mu p \pi^-$$

$$\nu_\mu p \rightarrow \nu_\mu n \pi^+$$

→ *Important backgrounds for MiniBooNE, K2K, atmospheric oscillation experiments*

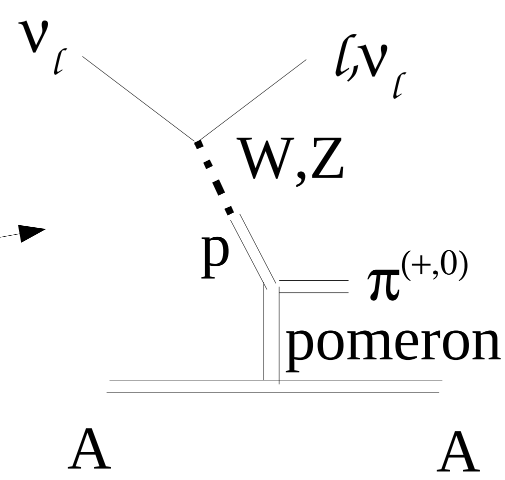
Multi pion production

→ important to separate these from single pion final states

Coherent pion production

NC or CC production

5% of total cross section



signature:
very forward
final state pion

→ theoretical model describing this based on PCAC theorem

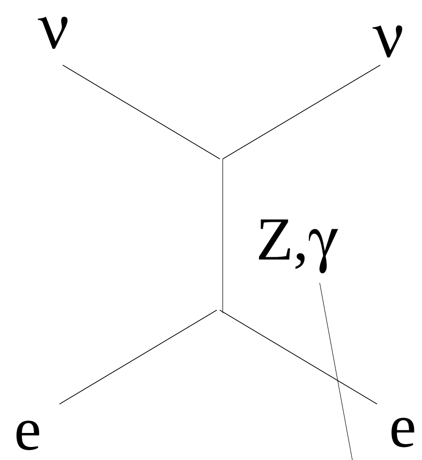
→ direct measurement of isovector axial-vector coupling β,

$$\frac{\sigma(\text{NC }\pi^0\text{ coherent})}{\sigma(\text{CC }\pi^+\text{ coherent})} = \frac{1}{2}\rho^2\beta^2$$

β previously measured to 10-20%

→ *Provides test of PCAC theorem and standard model parameter,* β

Neutrino electron elastic scattering



measure:
→ total cross section
→ shape of differential cross section

→ look for non-zero neutrino magnetic moment

- not enough statistics
- how low can we measure electron recoil energy?

→ *Engineering run for future neutrino magnetic moment measurement*

Small experiment........

Building costs:

$720,000 for a 30 x 30 ft building
at beam level (~25 ft below grade)

estimate comes from Jeff Sims from FESS
$300-$500/sq. ft., x2 to put the building below ground

Detector costs:

K2K recently built a 15 ton,
extruded scintillator detector:$1.5 million
x2 for labor, contingency, etc

$3 million for the detector

Total cost: under 4 million!

Authors on Expression of Interest for FINeSE presented to Fermilab PAC in November 2002

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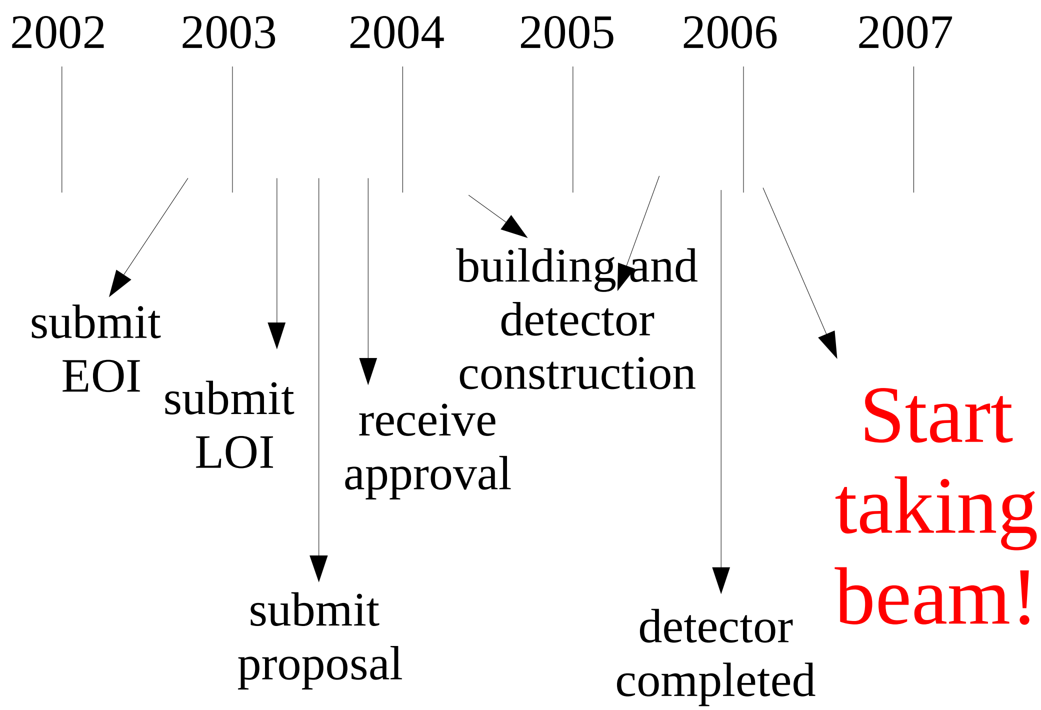
A number of HEP and Nuclear university groups as well as National Labs are interested in this project

Argonne National Lab
Columbia University
Fermi National Lab
Indiana University
Louisiana State University
Los Alamos National Lab
New Mexico State University

Looking for more interested collaborators!

FINeSE Timeline

We have an existing and running neutrino beam,
we need an aggressive schedule:



Lots of good physics to do at low neutrino energies
Booster Neutrino Beamline is the only place in the world to do this!

With a relatively simple detector

→ Δs measurement

→ wealth of cross section physics

→ enhancement of the miniBooNE measurement!

FINeSE!